

Remarks

Claims 79 and 100 have been amended as shown above. Support for the amendment to claim 79 may be found in the Third Substitute Specification at, e.g., paragraphs 0009 and 0074, and in the October 18, 1999 Specification at, e.g., page 3, lines 6-8 and page 11, line 29 through page 12, line 2. The claim 100 amendment is editorial in nature. Following entry of this amendment, claims 39, 40, 50, 73-76 and 79-146 will be pending in this application with claims 1-38, 41-49, 51-72, 77 and 78 having been cancelled and claims 39, 40, 50, 73-76, 84-99 and 101-146 having been withdrawn from consideration.

Applicant thanks the Examiner for extending to applicant, the undersigned attorney and attorney Pamela L. Stewart the courtesy of an in-person interview on Wednesday, November 16, 2005. The substance of the interview is correctly set forth in the Interview Summary prepared by the Examiner at the interview. The interview also involved the amendments shown above and the arguments set out below.

Rejection of Claims 79-83 and 100 under 35 U.S.C. §103(a)

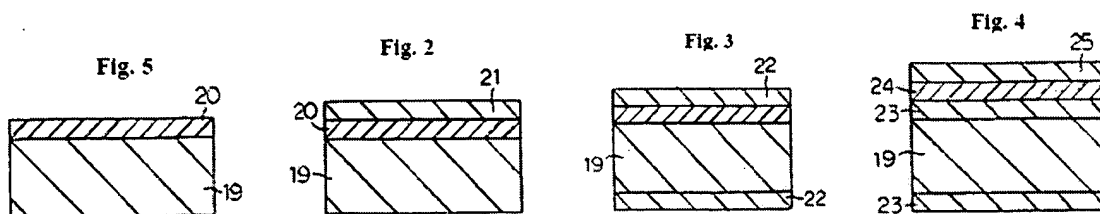
Claims 79-83 and 100 were rejected under 35 U.S.C. §103(a) as being unpatentable over Japanese Published Application No. JP 4-48515 (JP'515), on grounds *inter alia* that:

“JP'515 teaches a transparent conductive film used for EL or light emitting displays wherein the transparent conductive film provides an improved barrier for the display. JP'515 teaches that the transparent conductive film is formed by depositing a vacuum-evaporated, plasma polymerized polymer layer onto the surface of either a substrate film such as a polyester film or the transparent conductive film or both wherein the transparent conductive film is indium oxide or tin-doped indium oxide (ITO) and is formed on the polyester film (Page 4-6 of English Translation.) JP'515 further teach that after forming the transparent conductive film and the plasma polymerized polymer layer(s) on the substrate, additional layers including a light emitting layer, a dielectric layer, and a back electrode layer are formed followed by a protective film covering the entire laminate, wherein the transparent conductive film or electrode is connected to the rear electrode to achieve light emission (Pages 4 and 7.) JP'515 does not specifically teach that the laminate comprises two

transparent conductive oxide films separated by the plasma polymerized polymer layer, however, one having ordinary skill in the art at the time of the invention would have been motivated to determine the optimum number of barrier layers to provide the desired barrier properties for the display.” (see the Final Rejection at pages 2-3).

Reconsideration is requested. JP’515 does not discuss or attribute barrier properties to its conductive oxide layer. JP’515 does say that moisture is one of the causes of reduction in luminous intensity in a light-emitting layer of an EL display (see the translation at page 4, second paragraph from the bottom of the page), and says that prior methods for solving this problem include (1) “a method where an ethylene vinyl alcohol copolymer or epoxy acrylate resin, trifluoromonochloroethylene, vinylidene chloride, etc. is dissolved in a solvent and coated onto the surface of a polyester film using a wet coating method” (see page 4, last paragraph) and (2) “a method where an inorganic material such as SiO₂, TiO₂ and Al₂O₃ is deposited by means of vacuum deposition” (see page 5, first paragraph). JP’515 then says that it is difficult to automate method 1 (see page 5, first paragraph), and says that the deposition step in method 2 increases production cost and requires at least a 1000 Å film thickness, but that the resulting film “becomes hard with increased thickness and cracks are likely to form” (see page 5, first paragraph).

JP’515 next says that its invention is “to provide a method of producing a transparent conductive film characterized by the fact that a **water repellent polymer** is deposited onto the surface of either the film or the transparent conductive film or both in the manufacture of a transparent conductive film where a transparent conductive film is formed on a polyester type film by means of deposition” (see page 5, third paragraph, emphasis added). JP’515 includes a comparison example in which only **one** ITO layer and no water repellent polymer layers are employed (see the “Prior art” Example at the middle of page 8 and Fig. 5, shown below). The working examples in JP’515 add **one, two or three** water repellent polymer layers to the Fig. 5 **one** ITO layer film (see Working Example 1, Working Example 2, Working Example 3 and Figs. 2-4, shown below):



As this sequence shows, JP'515 starts with a single layer ITO film, and adds one, two or three water repellent polymer layers. JP'515 describes using ITO as a transparent conductive layer (*viz.*, as an electrode). JP'515 nowhere says to use ITO as a barrier, and nowhere uses and nowhere suggests using more than one transparent conductive oxide layer. If asked to consider the matter, a person having ordinary skill in the art who reviewed JP'515 would assume that using more than one transparent conductive oxide layer (e.g., more than one ITO layer) would be highly undesirable since doing so would increase the ITO production cost and might also cause the film to become harder or more prone to crack formation (see the page 5 excerpts mentioned above).

JP'515 identifies its polymer layers as "water repellent" but does not describe the ITO layer as being water repellent, as being a "barrier" layer or as providing "barrier properties". If asked to consider the matter, a person having ordinary skill in the art would assume that JP'515's ITO layer would not serve as a "barrier" layer or provide "barrier properties" since it is only 500 Å thick (see page 7, seventh paragraph) whereas JP'515 says that an inorganic oxide layer must be at least 1000 Å thick to provide the desired "effect" (*viz.*, preventing moisture absorption, see the paragraph spanning pages 4-5). If a person having ordinary skill in the art who reviewed JP'515 were asked to "determine the optimum number of barrier layers to provide the desired barrier properties for the display" as proposed in the Final Rejection, that person would do so by varying the number of water repellent **polymer** layers. Such a person would not be motivated by JP'515 to add (and in fact would be motivated by JP'515 **not** to add) an additional ITO layer or to determine an optimum number of ITO layers.

The Final Rejection also asserted that:

"With respect to claim 81, though JP'515 teaches that a protective resin film such as trifluorochloroethylene is provided over the entire laminate, one having ordinary

skill in the art at the time of the invention would have been motivated to utilize any conventional resin film typically utilized in the art as a protective layer, such as an acrylic hardcoat, in producing the laminate taught by JP'515.” (see the Final Rejection at page 3).

Reconsideration is requested. JP'515 says that trichloroethylene resin can provide a protective film. No showing has been made that a person having ordinary skill in the art would disregard this aspect of JP'515 and would instead replace the trichloroethylene resin protective layer in JP'515 with an acrylic hardcoat as recited in claim 81.

The Final Rejection also asserted that:

“JP'515 does not specifically teach a sheet resistance as instantly claimed, however, considering the laminate taught by JP'515 is a light emitting device as instantly claimed, one skilled in the art would have been motivated to utilize routine experimentation to determine the desired sheet resistance for the transparent conductive oxide layer wherein one would expect the value to fall within the instantly claimed range in order to provide the desired electrode properties for light emission.” (see the Final Rejection at page 3).

Reconsideration is requested. Applicant provides extensive discussion concerning sheet resistance, resistivity and their relationship to permeability (see e.g., applicant's enclosed **FIG. 15, FIG. 18, FIG. 21** through **FIG. 31** and the text beginning at paragraph 0086). However, JP'515 says nothing regarding sheet resistance or variation in sheet resistance. A person having ordinary skill in the art who reviewed JP'515 would have no information whatsoever concerning sheet resistance or a “desired” sheet resistance, and no basis whatsoever for determining a desired sheet resistance or for engaging in the experimentation proposed in the Final Rejection.

The Final Rejection also asserted that:

“In addition, it would have been obvious to one having ordinary skill in the art to utilize the same transparent conductive oxide film for both electrodes wherein JP'515 teaches that a plasma polymerized layer is formed over the first transparent electrode layer between the electrodes as discussed above.” (see the Final Rejection at page 3).

Applicant will assume that these comments were directed towards claim 100. The second (back) electrode in the JP'515 EL device is made from aluminum foil (see page 7, fourth paragraph). Such an electrode can provide very good moisture resistance and a reflective surface that prevents light loss through the back of the device, but is not said to be transparent. A person having ordinary skill in the art would not be motivated or enabled by JP'515 to form a device having "transparent conductive oxide film for both electrodes" for at least the reason that the device might have less light output than JP'515's aluminum foil-backed device..

The Final Rejection also asserted that:

"Lastly, with respect to Claim 100, the Examiner takes the position that the invention taught by JP'515 includes a device comprising two sides wherein the first side has the TCO/plasma polymerized barrier and the other side has multiple layers comprising the protective film, i.e. "A" composite barrier, and hence reads upon the instant claim considering the claim recites "wherein the device has two sides each of which is protected by a composite barrier".

Reconsideration is requested for the reasons explained in the prior paragraph. JP'515 does not show or suggest a device like that of claim 100.

Applicant accordingly requests withdrawal of the 35 U.S.C. §103(a) rejection of claims 79-73 and 100 as being unpatentable over JP'515.


Conclusion

JP'515 starts with a single layer ITO film, and adds one, two or three water repellent polymer layers. JP'515 nowhere uses and nowhere suggests using more than one transparent conductive oxide layer, and does not make obvious a device of rejected claims 79-83 or 100.

The Examiner is encouraged to call the undersigned attorney if there are any questions regarding this application or this amendment.

Respectfully submitted on behalf of
3M Innovative Properties Company,

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| Registration Number | Telephone Number: |
| 29,524 | 612-331-7412 |
| Date | |
| November 21, 2005 | |

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Amendments to the Drawing

Please replace the entire Drawing with the accompanying Replacement Sheets 1-30. **FIG. 1** through **FIG. 13**, **FIG. 14a**, **FIG. 14b** and **FIG. 14c** have been redrawn to conform more closely to USPTO drawing requirements. **FIG. 15** through **FIG. 18** have been similarly redrawn and the vertical axes have been relabeled to identify oxygen permeability or water permeability. **FIG. 19** and **FIG. 20** are redrawn versions of Appendix D, pages 1 and 2 in the October 18, 1999 application. **FIG. 21** through **FIG. 26** are redrawn versions of **FIG. 14** through **FIG. 19** in the October 18, 1999 application. **FIG. 27** through **FIG. 31** are redrawn versions of **FIG. 20** through **FIG. 24** in the October 18, 1999 application. **FIG. 32** through **FIG. 36** are redrawn versions of Appendix E, pages 1-5 in the October 18, 1999 application. **FIG. 37** is a redrawn version of Appendix A, page 1 in the October 18, 1999 application.



TRANSPARENT CONDUCTIVE OXIDES FOR PLASTIC FLAT PANEL DISPLAYS

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application is a divisional of U.S. Patent Application Serial No. 09/419,870 filed October 18, 1999, now abandoned, which in turn claims the benefit of U.S. Provisional Application No. 60/106,871, filed November 2, 1998, the disclosures (including appendices) of which are incorporated herein by reference. Further, this application incorporates by reference the content of the following: U.S. Patent No. 5,440,446, issued August 8, 1995, U.S. Patent No. 5,725,909, issued March 10, 1998, U.S. Patent Application No. 08/706,180, filed August 30, 1996 (now U.S. Patent No. 6,231,939), and U.S. Patent Application No. 08/741,609, filed October 31, 1996 (now abandoned, and refiled as a continuation on November 26, 2003, as U.S. Patent Application Serial No. 10/723,321).

FIELD OF THE INVENTION

[0002] This invention relates to composite substrates for flat panel displays (FPDs), packaging materials and light sources (electro luminescence lamps) comprising a plastic substrate having thin film barrier and conductive layers, in particular, multiple thin alternating layers of metallic film, transparent conductive oxide (TCO), metal nitride, and organic polymers deposited over the plastic substrate.

BACKGROUND OF THE INVENTION

[0003] The use of portable electronic devices incorporating flat panel displays is prevalent and increasing rapidly. Because of the portable nature of these devices, it is desired to minimize both the size and weight and maximize durability. The display portion of the device is generally larger and denser as compared to the rest of the device, and is manufactured on

glass substrates. Accordingly, a smaller, lighter and more durable portable electronic device is most effectively achieved with a smaller, lighter and shatterproof electronic device display.

[0004] Despite being lightweight, plastic has not been considered a viable substrate material to be used for the manufacture of flat panel displays for multiple reasons. Most importantly, flat panel displays fabricated with plastic substrates tend to fail prematurely due to degradation of display medium (display matrix) and/or metallic electrodes. In particular, the display medium and some metallic electrodes ~~and the display medium which is often positioned between the electrodes~~, become degraded when atmospheric oxygen and water vapor permeate the substrate and chemically degrade the active portion of the display matrix which is generally comprised of liquid crystals and/or light emitting devices. In addition, common optical quality plastic substrates, e.g. polyethylene terephthalate (PET), have limited thermal properties. In particular, there is a limited temperature range that allows useful optical quality (e.g. clarity, transparency, and uniform index of refraction) to be maintained, while maintaining the ~~substrate's~~ substrate's mechanical strength and properties.

SUMMARY OF THE INVENTION

[0005] The present invention is directed to the fabrication of flat panel displays on lightweight, flexible, plastic substrates. Because plastic substrates for FPDs are flexible, smaller and lighter than glass substrates, the electronic device with the plastic FPD is more portable, space-efficient and lightweight. In addition, electroluminescent and organic light emitting devices fabricated on flexible polymeric substrates in a coating process have lower manufacturing costs than those with glass substrates, and improved ruggedness.

[0006] A display medium of the flat panel display is sandwiched between two electrode layers. At least one of the electrodes is transparent for viewing of the display. The display medium is protected from oxidative or moisture degradation. In the present invention, at least one layer, having both barrier characteristics and the ability to function as an electrode, is deposited over the substrate. In particular, the layer has both low oxygen and water vapor permeability, and a low enough resistivity to function as an electrode for the display. For lower permeability and/or higher conductivity, multiple alternating layers of barrier materials

and conductive materials are applied. In an alternative embodiment, the conductive layers (e.g. transparent conductive oxide layers) are in direct electrical contact. The barrier material includes at least one of an organic polymer, a transparent dielectric, a transparent metal nitride and/or a transparent conductive oxide. The conductive material includes at least one of a thin transparent conductive oxide, a thin transparent metallic film and/or a metal nitride.

[0007] Using a smoothing base coat layer over the plastic substrate imparts good optical quality throughout the substrate layers and provides a pristine surface for nucleation of the deposited barrier or conductive layer, e.g. TCO. The pristine surface ~~smooths~~smoothes over any surface roughness of the plastic substrate, thereby adding to the FPD lifetime and optical quality. Additionally, a hardcoat layer is applied over the substrate in lieu of or in addition to the smoothing basecoat layer.

[0008] ~~The smoothing basecoat and hardcoat~~ various described organic layers may be applied by ~~one of~~ many well known non-vacuum liquid coating processes, e.g. preferably by Gravure, or fabricated through a vacuum coating technique, e.g., preferably by a polymer multilayer (PML) coating process. Related desirable coating processes are disclosed in U.S. Patents 5,547,508, 5,395,644, 5,260,095, U.S. Patent Application ~~Number~~Serial No. 08/939,594, filed September 29, 1997, entitled "Plasma enhanced chemical deposition with low vapor pressure compounds", now U.S. Patent No. 6,224,948 and herein incorporated by reference, Thin Film Processes ~~II~~II, chapters ~~II-2, 4, 5, and IV-1~~II-2, 4, 5, and IV-1, edited by John L. Vossen and Wermer Kern, Academic Press, 1991, ISBN 0-12-728251-3, and Deposition Technologies for Films and Coatings, Developments and Applications, Rointan F. Bunshah et al., Chapters 5, 6, 8 and 9, Noyes Publications, 1982, ISBN 0-81-55-0906-5.

The ~~terms PML and PML process as used in this application are generic and mean any form of a PML process, including Plasma PML processes (PPML processes) and liquid PML processes (LML processes).~~ The basic vacuum evaporation PML process ~~is~~may be used to deposit organic monomers over the plastic substrate. The organic monomer is then polymerized in-situ by electron beam, ~~a plasma process,~~ or UV radiation.

[0009] The PML process is compatible with physical vapor deposition processes for layers such as TCO layers. Both processes are carried out in combined sequences within a

properly designed single vacuum chamber. ~~However, often multiple vacuum chambers are may be used, for example, if a substrate is hardcoated previously.~~

[0010] The PML deposited organic polymer layer is used to produce substrate surface smoothing and improve barrier coatings in the multilayer structure. The benefit of a smooth substrate surface is that there is a clean surface for adhesion, nucleation, and growth of a deposited ~~barrier or~~ conductive layer, e.g. a TCO. Additionally, a PML deposited organic polymer layer provides protection of an underlying barrier layer in order to minimize holes or other defects in the layer so that there is low permeability.

[0011] Neither a single layer barrier coating with a metal oxide layer such as thin film dielectric coatings of alumina or silica or other certain metal oxides, nor a plastic flat panel display with a thick metallic film layer having an optical density of greater than 2.0, renders low enough permeability for the processing and manufacture of plastic flat panel displays with acceptable lifetimes. Even where ~~a single thick layer or multiple thin layers~~ of dielectrics, metals or the combination thereof are used, the improvement in performance is minimal. In order to provide barrier properties sufficient for optical quality plastic flat panel displays, a transparent dielectric barrier, such as SiO_{2-x} or $\text{Al}_2\text{O}_3/\text{Al}_2\text{O}_{3-y}$, is deposited over a plastic substrate. When dielectric layers are combined with PML deposited organic polymer layers, outstanding barrier properties are achieved on flexible plastic substrates. Alternatively to the dielectric layer, a barrier coating of ITO (called "indium tin oxide," which is actually "Tin tin doped indium oxide," a mixture of indium oxide and tin oxide) or another TCO barrier is deposited over the substrate. In yet another alternative embodiment, both TCO barrier layers and PML processed organic polymer layers are deposited over the plastic substrate. Moreover, in yet another alternative, both TCO barrier layers with PML processed organic polymer layers and the transparent dielectric barrier layers are deposited over the plastic or polymeric substrate. Multilayer structures of such organic and inorganic layers deposited over a plastic substrate exhibit significantly improved barrier properties as compared to inorganic, organic, or metallic layers alone.

[0012] In an embodiment, a PML processed top coat polymer layer is applied before the previously deposited layer contacts a surface, such as a roller, thereby protecting the

previously deposited layer. The PML processed top coat greatly enhances the exclusion of moisture (water vapor) and atmospheric gases that chemically degrade the display medium and decrease the device performance, even though the polymer topcoat is not, itself, a good barrier material.

[0013] Metal oxide dielectric barriers have previously been deposited by evaporation, sputtering, and chemical vapor deposition processes onto glass substrates. However, for achieving metal oxide thin films with bulk material-like properties on glass substrates, a high temperature deposition method is used, which would melt the plastic substrate, thereby negatively impacting the mechanical properties of the plastic substrate. In the present invention, the PML ~~family of processes~~ process used for depositing an organic dielectric does not require such high temperatures and therefore does not significantly alter the mechanical properties of the plastic substrate. However, organic polymer layers alone do not provide substantial barrier properties, particularly against water vapor.

When TCOs are deposited at low temperatures to accommodate the thermal and mechanical limits of the substrate, for example, by magnetron sputtering, electron-beam evaporation or plasma enhanced chemical vapor deposition (PECVD), the subsequent TCO coatings have less than bulk conductivity, i.e. low overall levels of conductivity.

[0014] TCO films with a larger thickness deposited through these methods achieve acceptable conductive levels for portable electronic devices. However, these thick films of TCO are subject to cracking, crazing and, in some instances, delamination from the substrate, especially when they are processed by a heat treatment step or a coating process involving mechanical rollers (e.g. web coating). Accordingly, the TCO coating is deposited in a series of thin, separated layers, yet still maintains high conductive levels. Multiple thin layers of TCO avoid the problems associated with thicker layers, and advantageously are electrically connected in parallel to provide adequate electrical performance characteristics.

The thin layers of TCO are preferably separated by layers deposited ~~in combination with layers from~~ using the PML process, which leads to improved optical, electrical and mechanical performance. ~~In particular, the polymer layers separate the TCO layers.~~ Superior surface properties (low surface roughness, and high optical quality), barrier properties (low

vapor permeability) and mechanical properties result when TCO coatings are deposited by magnetron sputtering on a plastic substrate in combination with the PML process-

[0015] , e.g., by providing hydrogen in the plasma of the vacuum chamber used in the sputtering process of the TCO. Preferably, moderate annealing temperature conditions, with respect to substrate limits, are used for TCO (including ITO, "tin-doped indium oxide") deposition because high. For example, the resistivity of ITO is a function of the oxygen and tin content, as well as the deposition conditions (e.g., temperature conditions result in melting of the plastic, and low). Low temperature conditions yields depositions yield high resistivity ITO layers with undesirable high resistivity. (The resistivity of ITO is a function of the oxygen and tin content, as well as the deposition conditions, such as temperature). A low resistivity for the ITO layers is desired. The resistivity of ITO decreases with a thicker TCO layer. But as discussed previously, thick TCO layers are prone to cracking or crazing. Multiple thin layers of TCO, as described in the present invention, will not crack and will yield a lower resistivity. Moreover, the surface resistivity of a thin film of TCO in multiple layers is low for a given total film thickness, due to its improved microstructure.

[0016] In a first embodiment of the present invention, a polymer smoothing coating is deposited over the substrate. The smoothing coating is applied by a PML process or liquid coating. A TCO, metal nitride, or metal layer is then deposited over the smoothing layer. Additionally, multiple alternating layers of a protective polymer layer and an additional TCO, metal nitride, or metal layer ~~is~~ are deposited. Preferably, the alternating layers are of the same material, e.g. TCO/polymer/TCO, etc.

[0017] In a second embodiment, multiple alternating layers of polymer layers and metal oxide or metal nitride are deposited over the substrate or a polymer smoothing coating layer. A TCO layer is then deposited over the top of multiple alternating layers. These multiple alternating layers together with the TCO have adequate barrier and conductivity characteristics.

In a third embodiment, a substrate is coated with a TCO layer, a metal coating, and another TCO layer. This three layer configuration is called "optically enhanced metal," ~~or an induced transmission filter~~ and has similar characteristics as ~~and is substitutable for a single~~

TCO layer. With the optically enhanced metal good conductivity, optical transmission and barrier properties are achieved. A ~~similar structure using metal nitrides~~ metal nitride layer may be substituted for one or more of the metal coating or the TCO layer, ~~or one or more metal oxide layers substituted for one or more TCO layers, functions equivalently to~~ in the optically enhanced metal- configuration. For example, a further embodiment is ~~comprised of an~~ optically enhanced metal configuration may be made from a TCO layer, a conductive metal nitride layer and another TCO layer-

[0018] ~~Alternatively, the structure is,~~ or from a silicon nitride layer, a metal layer and another metal nitride layer.

[0019] In a fourth embodiment, a substrate is alternatively coated with an inorganic layer (such as TCO, metal nitride, or dielectric metal oxides), and polymer layers to provide both barrier and conductive properties.

BRIEF DESCRIPTION OF THE DRAWINGS

[0020] The aspects of the present invention described above in summary and below in more detail as well as various advantageous aspects will become appreciated as the same becomes better understood with reference to the specification, claims and drawings wherein:

~~FIG. 1 is a cross sectional view of a composite substrate for a flat panel display (FPD) of the present invention;~~

~~FIG. 2 is a cross sectional view of another embodiment of conductive barrier layer 3 of FIG. 1;~~

~~FIG. 3 is a cross sectional view of another embodiment of conductive barrier layer 3 of FIG. 1;~~

~~FIG. 4 is a cross sectional view of another embodiment of conductive barrier layer 3;~~

~~FIG. 5 is a cross sectional view of another embodiment of conductive barrier layer 3 of FIG. 1;~~

~~FIG. 6 is a cross sectional view of an embodiment of a conductive barrier layer;~~

~~FIG. 7 is a cross sectional view of an embodiment of conductive barrier layers of FIG.~~

~~1;~~

~~FIG. 8 is a cross-sectional view of an embodiment of conductive barrier layers of FIG. 1;~~

~~FIG. 9 is a cross-sectional view of an embodiment of conductive barrier layers of FIG. 1;~~

~~FIG. 10 is a cross-sectional view of an embodiment of conductive barrier layers of FIG. 1;~~

~~FIG. 11 is a cross-sectional view of an embodiment of conductive barrier layers of FIG. 1;~~

~~FIG. 12 is a cross-sectional view of an embodiment of conductive barrier layers;~~

[0021] FIG. 1 is a cross-sectional view of a flat panel display (FPD) of the present invention;

[0022] FIG. 2 through FIG. 5 are cross-sectional views of other embodiments of conductive barrier layer 3 of FIG. 1;

[0023] FIG. 6 is a cross-sectional view of an FPD of the present invention;

[0024] FIG. 7 through FIG. 12 are cross-sectional views of other embodiments of conductive barrier layer 3 of FIG. 1;

[0025] FIG. 13 is a schematic illustration of a coating apparatus for forming the conductive barrier layer of FIG. 1;

[0026] FIG. 14a is a schematic illustration of a laminating process for the FPD of FIG. 1;

[0027] FIG. 14b is a cross-sectional view of the FPD before undergoing a bonding process;

[0028] FIG. 14c is a cross-sectional view of the FPD after undergoing a bonding process;

[0029] FIG. 15 is a chart showing water vapor permeability of an-ITO film and ITO/Ag/ITO films deposited on a polyethylene terephthalate (PET) substrate versus ITO film sheet resistance;

[0030] FIG. 16 is a chart showing water vapor permeability of ITO film and ITO/Ag/ITO films deposited on a PET substrate versus ITO film thickness;

[0031] FIG. 17 is a chart showing oxygen permeability of ITO film deposited on a PET substrate versus ITO film thickness;

[0032] FIG. 18 is a chart showing oxygen permeability of ITO film deposited on a PET substrate versus ITO film sheet resistance;

~~FIG. 19 is a chart showing transmittance and reflectance spectra (for an ITO layer over a silver film layer over an ITO layer over a PET substrate at a sheet resistance of 14 Ohms/Square) versus wavelength;~~

~~FIG. 20 is a chart showing transmittance and reflectance spectra (for an ITO layer over a PET substrate at a sheet resistance of 29 Ohms/Square) versus wavelength;~~

~~FIG. 21 is a chart showing transmittance and reflectance spectra (for an ITO layer over a PET substrate at a sheet resistance of 57 Ohms/Square) versus wavelength;~~

~~FIG. 22 is a chart showing transmittance and reflectance spectra (for an ITO layer over a PET substrate at a sheet resistance of 65 Ohms/Square) versus wavelength; and~~

~~FIG. 23 is a chart showing transmittance and reflectance spectra (for an ITO layer over a PET substrate at a sheet resistance of 347 Ohms/Square) versus wavelength.~~

[0033] FIG. 19 is a chart showing oxygen permeability of ITO films deposited on a PET substrate versus ITO film thickness;

[0034] FIG. 20 is a chart showing water vapor permeability of ITO films deposited on a PET substrate versus ITO film thickness;

[0035] FIG. 21 is a chart showing sheet resistance of various substrates versus oxygen flow rate through the respective substrate;

[0036] FIG. 22 is a chart showing resistivity of various substrates versus oxygen flow rate through the respective substrate;

[0037] FIG. 23 is a chart showing sheet resistance of various substrates versus oxygen flow rate through the respective substrate for 7.5% hydrogen in the plasma;

[0038] FIG. 24 is a chart showing resistivity of various substrates versus oxygen flow rate through the respective substrate for 7.5% hydrogen in the plasma;

[0039] FIG. 25 is a chart showing sheet resistance of various substrates versus oxygen flow rate through the respective substrate for 20% hydrogen in the plasma;

[0040] FIG. 26 is a chart showing resistivity of various substrates versus oxygen flow rate through the respective substrate for 20% hydrogen in the plasma;

- [0041] FIG. 27 is a chart showing transmittance and reflectance spectra (for an ITO layer over a silver film layer over an ITO layer over a PET substrate at a sheet resistance of 14 Ohms/Square) versus wavelength;
- [0042] FIG. 28 is a chart showing transmittance and reflectance spectra (for an ITO layer over a PET substrate at a sheet resistance of 29 Ohms/Square) versus wavelength;
- [0043] FIG. 29 is a chart showing transmittance and reflectance spectra (for an ITO layer over a PET substrate at a sheet resistance of 57 Ohms/Square) versus wavelength;
- [0044] FIG. 30 is a chart showing transmittance and reflectance spectra (for an ITO layer over a PET substrate at a sheet resistance of 65 Ohms/Square) versus wavelength;
- [0045] FIG. 31 is a chart showing transmittance and reflectance spectra (for an ITO layer over a PET substrate at a sheet resistance of 347 Ohms/Square) versus wavelength;
- [0046] FIG. 32 is a chart showing transmittance and reflectance spectra (for a 25 nm thick semi-reactively sputtered ITO layer over a polymer layer on a PET substrate) versus wavelength;
- [0047] FIG. 33 is a chart showing transmittance and reflectance spectra (for a 153 nm thick semi-reactively sputtered ITO layer over a polymer layer on a PET substrate) versus wavelength;
- [0048] FIG. 34 is a chart showing transmittance and reflectance spectra (for a 134 nm thick semi-reactively sputtered ITO layer on a PET substrate) versus wavelength;
- [0049] FIG. 35 is a chart showing transmittance and reflectance spectra (for a 50 nm total ITO thickness barrier coating of semi-reactively sputtered ITO/polymer/semi-reactively sputtered ITO/polymer on a PET substrate) versus wavelength;
- [0050] FIG. 36 is a chart showing transmittance and reflectance spectra (for a 299 nm total ITO thickness barrier coating of semi-reactively sputtered ITO/polymer/semi-reactively sputtered ITO/polymer on a PET substrate) versus wavelength; and
- [0051] FIG. 37 is a chart showing deposition temperature capabilities of various plastic substrates.

DETAILED DESCRIPTION OF THE INVENTION

[0052] A flat panel display (FPD) **11**, of the present invention as shown in **FIG. 1**, employs ~~at least one~~ lightweight, flexible, plastic substrate-substrates **38** for fabricatingconstructing FPDs. In ~~one embodiment, the plastic is flexible. In another embodiment, the substrate used in the flat panel display is glass. In an alternative embodiment, there are~~between two plastic substrates used to construct the FPD. In between two substrates**38** of the flat panel display are at least two electrodes **3**. At least one of the electrodes is transparent for viewing of the display. A display medium **2** for the flat panel display is usually positioned between the two electrodes **3**. The display medium, as well as some electrode material, are protected from oxidative degradation and reaction with or incorporation of moisture.

[0053] The displays are fabricated using plastic substrates such as various polyolefins, e.g. -polypropylene (PP), various polyesters, e.g. ~~polyethylene terephthalate (PET), polymethylmethacrylate (PMMA)~~ and other polymers such as polyethylene naphthalate naphthalate (PEN), polyethersulphone (PES), polyestercarbonate (PC), polyetherimide (PEI), polyarylate (PAR), polyimide (PI), and polymers with trade names ARTON[®]™ (Japanese Synthetic Rubber Co., Tokyo, Japan) and AVATRELTM™ (B.F. -Goodrich, Brecksville, Ohio). See Appendix A for **FIG. 37** shows deposition temperature capabilities of the particularsome of these plastic substrates.

[0054] In the present invention, at least one layer, a conductive barrier layer **3** has both barrier characteristics (to protect the display medium and/or the metal electrode from oxidative degradation and reaction with or incorporation of moisture) and the ability to function as an electrode. The conductive barrier layer is deposited over the substrate to form a composite substrate, as shown in **FIG. 6**. In particular, layer **3** has both low oxygen and moisture (water vapor) permeability, and a low enough resistivity to function as an electrode for the display.

[0055] As shown in the general embodiments of **FIGs. 2** through **FIG. 5**, conductive barrier layer **3** comprises at least one sublayer ~~3~~**31** deposited over the substrate, for instance a single ITO layer. In an embodiment, at least one pair of sublayers, a dyad, of a polymer layer **24** and a layer of TCO **22**, metal **12**, metal nitride **14** or metal oxide **16**, is deposited over the

substrate. ~~Fig~~**FIG. 2** illustrates the sublayer having a dyad of metal **12** and metal oxide **16**. ~~Fig~~**FIG. 3** illustrates the sublayer having a dyad of metal nitride **14** and metal oxide **16**. ~~Fig~~**FIG. 4** illustrates the sublayer having a dyad of dielectric **17** and TCO **22**. ~~Fig~~**FIG. 5** illustrates the TCO layer **22** deposited over the dielectric layer **17** which is deposited over the polymer layer **24**. The sublayers ~~3~~**31** deposited on either side of the pairs illustrated in ~~Figs~~**FIG. 2- through FIG. 4** are, for example, ~~h~~a single ITO layer, additional dyads of the same materials, and/or a polymer coating. In an exemplary embodiment, multiple alternating sublayer pairs, comprised of the same materials as the original sublayer pair, are deposited over the substrate or over the previously deposited sublayer. ~~In another embodiment the multiple alternating sublayer pairs deposited over the previously deposited sublayer comprise different sublayer materials than the previously deposited sublayer.~~

[0056] There are a myriad of possibilities for materials comprising the sublayers of the conductive barrier layer. **FIGs. 2- through FIG. 5** illustrate generally only some of the more preferred embodiments of sublayer ~~3~~**31** materials for conductive barrier layer **3**, while **FIGs. 7- through FIG. 12** illustrate particularly the more preferred embodiments for the conductive barrier layer.

In one embodiment shown in ~~Fig~~**FIG. 9**, for example, a base coating **20** is deposited over the substrate **38**. The base coating is a polymer smoothing coating applied by a PML process and/or an organic hardcoat. The base coating can be deposited by a non_vacuum liquid coating process (to render a hardcoated PET) or applied by a PML process. When a hardcoat is deposited, the plastic substrate is rendered abrasion resistant. A TCO layer **22** (or metal layer **12**) is then deposited over the base coat. In another embodiment, multiple alternating layers of a protective polymer layer **24** and at least one TCO layer **22** (or metal layer **12**) are additionally deposited (see **FIG. 9**).

Preferably, the alternating layers additionally deposited are of the same material, e.g. **[0057]** TCO/polymer/TCO, etc. Alternatively, there is no base coat **20** for the embodiment of alternating layers of polymer/TCO/polymer (not shown) ~~in FIG. 9~~. In another embodiment, ~~also~~ (shown in **FIG. 9**), a metal conductor or reflector **12** overlays the top polymer layer **24**.

[0058] In the embodiment shown in **FIG. 7**, a substrate **38** is coated with a TCO layer **22**, a metal coating **12**, and another TCO layer **22**. This three layer configuration is called an ~~“optically enhanced metal,” or “induced transmission filter”~~ and has characteristics similar to a single TCO layer, ~~and is also substitutable for a single TCO layer~~. With the optically enhanced metal, good conductivity, transmission and barrier properties are achieved. In a preferred embodiment, deposited on the three layers is polymer layer **24** (see **FIG. 8**). The polymer layer **24** may be alternating with the optically enhanced metal (not shown).

Alternatively, base coat **20** is deposited over the substrate as shown in **FIG. 7**. Additionally or alternatively, another dyad (a metal and TCO pair) is deposited over the top TCO layer and/or an additional polymer layer **24** (a polymer overcoat) is deposited over the previously deposited dyad (see **FIG. 8**). In another alternative, a thick metal layer **12** is deposited over the polymer overcoat layer, as also shown in **FIG. 8**. Alternatively, the metal nitride layer **14** is substituted for one or more of the metal layers in the above described embodiments, for example, see **FIGs. 10 and FIG. 11**.

[0059] In still another embodiment, the substrate is alternatively coated with an inorganic layer (such as the TCO layer or the dielectric metal oxide layer), and polymer layers to provide both barrier and conductive properties.

[0060] **FIG. 12** illustrates metal layer **12** sandwiched between two metal nitride layers **14**. Alternatively, additional dyads (metal and metal nitride pair) are deposited over the metal nitride layer. Further embodiments of this dyad pair are similar to the TCO/metal dyad pair embodiments of **FIGs. 7- and FIG. 8**, i.e. the TCO layers of **FIGs. 7- and FIG. 8** are replaced by one or more metal nitride layers.

[0061] In another alternative embodiment, the dielectric layer replaces one or more TCO layers in the above described embodiments (see generally **FIGs. 4 and FIG. 5**). As shown in **FIG. 5**, multiple alternating layers of dielectric **17** and polymer layers **24** are deposited over the substrate **38**. The number of multiple alternating layers (or dyads) vary, and is represented here by ~~3~~**31**, sublayers of the conductive barrier layer **3**. A TCO layer **22** (or metal layer **12**) is then deposited over the top of multiple alternating layers. These multiple alternating layers

together with the TCO have adequate barrier and conductivity characteristics as described in more detail below.

Each TCO layer **22** of the above embodiments is a single TCO layer.

[0062] Alternatively, the TCO layers in the Figures described above represents the thickness of two TCO layers from adjacent layers of “optically enhanced metal” of **FIG. 8** or the metal nitride alternative of **FIG. 11**.

[0063] Preferably, the metal layers that are in the alternating dyad pairs or in between the TCO, metal nitride, or dielectric layers, are thin. ~~The~~In addition, metal layers that are adjacent the “display medium,” matrix, i.e. overlaying the dyad layers, ~~or on the substrate~~, have a greater thickness than the sandwiched metal layers.

[0064] Sublayer ~~3~~**31** materials that provide transparent barrier properties are thin transparent metal oxides **16**, and/or thin transparent metallic films **12**, and/or thin metal nitrides **14**, for example silicon nitride, and aluminum nitride. The polymer layer **24** enhances barrier properties by reducing the number of holes and defects in the films upon which or under which, they are deposited. The metal oxide layer **16** comprises the dielectric layer **17** and/or the transparent conductive oxide layer **22**. Thicknesses for the barrier layers are in the nanometer and angstrom range. Thicknesses for the PML deposited layers are in the micron and ~~sub-micron~~ range. For example, improved barrier coating occurs when a PML deposited organic polymer layer (a base coat), and/or a metal oxide layer is placed over the plastic substrate. See Table 2, shown below in the section entitled “Results of Conducted Experiments”

Sublayer ~~3~~**31** materials that provide conductive properties include the thin TCO layer **22**, a thin transparent metallic film layer **12** (such as aluminum, silver, copper, gold, platinum, palladium, and alloys thereof), and the metal nitride layer **14** (such as transition metal nitrides, for example, ~~titanium nitride, zirconium nitride, hafnium nitride, and nitrides of Group IIIA~~ Group IV elements of the Periodic Table, e.g. gallium nitride).

, silicon nitride and titanium nitride). Thicknesses for the conductive layers are in the nanometer and angstrom range.

[0065] Preferably the ~~conductive film (TCO)~~ is formed ~~by from~~ multiple thin ~~conductive~~ layers ~~(of TCO)~~ deposited with electrical contact to each other and separated by polymer layers. ~~The conductive (, so that a low resistivity is achieved and the TCO) layers are deposited with electrical contact to each other, so that a low resistivity is achieved.~~ Consequently, the ~~conductive film (TCO)~~ functions as both the electrode and a barrier.

[0066] In the preferred embodiment, the PML processed base coat **20** is deposited over the substrate as shown in **FIG. 9**. The base coat produces substrate smoothing, and more importantly, in combination with other layers, the base coat has surprisingly effective vapor barrier enhancement properties because of the smoothing and protection characteristics. The sublayers are preferably deposited in combination with the process illustrated in **FIG. 13**, as described below.

[0067] Using the smoothing base coat layer over the plastic substrate imparts good optical and barrier quality throughout the substrate layers and provides a pristine surface for nucleation of the deposited TCO electrode layer. The basecoat ~~smooths~~ smoothes over any surface roughness of the plastic substrate, thereby adding to the FPD lifetime, and optical quality.

[0068] In an exemplary embodiment, one or more metal oxide layers are replaced with ~~the~~ a TCO layer. When TCO coatings, including ITO ("Tin doped indium oxide"), cadmium oxides (~~CdSn₂O₄, CdGa₂O₄, CdIn₂O₄, CdSb₂O₆, e-G-e; CdSn₂O₄, CdGa₂O₄, CdIn₂O₄, CdSb₂O₆, CdGeO₄~~), tin oxides (~~various alloys and dopants thereof~~), indium oxides (~~In₂O₃: Ga, GaInO₃ (Sn, Ge), (GaIn)₂O₃~~), zinc oxides (ZnO(Al), ZnO(Ga), ZnSnO₃, Zn₂SnO₄, Zn₂In₂O₇, Zn₂In₂O₃, Zn₂SnO₄, Zn₂In₂O₅, Zn₃In₂O₆), and/or magnesium oxides (~~MgIn₂O₄, MgIn₂O₄ - Zn₂In₂O₅~~) are deposited on the plastic substrate at a low temperature, they have an amorphous microstructure. ~~For characteristics~~ Characteristics of the above TCO materials, ~~see Appendix B.~~ are shown below in Table A:

TABLE A

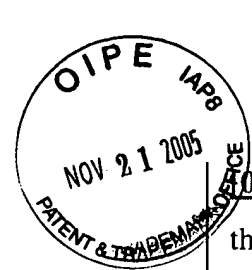
EMERGING TRANSPARENT CONDUCTING OXIDES FOR ELECTRO-OPTICAL APPLICATIONS

CHARACTERISTICS OF EMERGING TCO MATERIALS

| <u>Material</u> | <u>Trans. (%)</u> | <u>Resistivity</u> (x10 ⁻⁴ Ωcm) | <u>Carrier</u> <u>Conc.</u> (x10 ²⁰ cm ⁻³) | <u>Mobility</u> (cm ² /V-1s) | <u>Film</u> <u>Thickness</u> (nm) | <u>References</u> |
|--|-------------------------|---|---|--|---|---|
| <u>CdSn₂O₄</u> | <u>88</u> | <u>1.2</u> | <u>9.0</u> | <u>59.6</u> | <u>530</u> | <u>Wu, X. et al., JVST A 15(3), 1997</u> |
| <u>CdGa₂O₄</u> | | <u>83</u> | <u>10</u> | | | <u>Omata, T. et al., Appl. Phys. Lett.</u> <u>62(5), 1993</u> |
| <u>CdIn₂O₄</u> | <u>90</u> | <u>2.3</u> | <u>6.1</u> | <u>44.2</u> | <u>290</u> | <u>Wu, X. et al., JVST A 15(3), 1997</u> |
| <u>CdSb₂O₆ (Y)</u> | <u>90</u> | <u>240</u> | <u>1.3</u> | <u>1.9</u> | <u>170</u> | <u>Yanagawa, K. et al., Appl. Phys. Lett.</u> <u>65(4), 1994</u> |
| <u>Cd₂GeO₄</u> | <u>98</u> (Internal) | <u>1000</u> | <u>0.1</u> | <u>5</u> | | <u>Hosono, H. et al., Appl. Phys. Lett.</u> <u>67(18), 1995</u> |
| <u>ITO</u> | <u>91</u> | <u>1-2</u> | <u>10</u> | <u>37</u> | <u>140</u> | <u>Heiz, B., OIC Topical Meeting, 1998</u> |
| <u>ZnO(Al)</u> | <u>90</u> | <u>1.4</u> | <u>9.9</u> | <u>45</u> | <u>150</u> | <u>Imaeda, K. et al., 43rd AVS Symp.,</u> <u>1996</u> |
| <u>ZnO(Ga)</u> | <u>90</u> | <u>2.7</u> | <u>13</u> | <u>18</u> | <u>230</u> | <u>Imaeda, K. et al., 43rd AVS Symp.,</u> <u>1996</u> |

Third Substitute Specification

| <u>Material</u> | <u>Trans. (%)</u> | <u>Resistivity</u> ($\times 10^{-4} \Omega \text{cm}$) | <u>Carrier</u> <u>Conc.</u> ($\times 10^{20} \text{cm}^{-3}$) | <u>Mobility</u> ($\text{cm}^2/\text{V}\cdot\text{s}$) | <u>Film</u> <u>Thickness</u> (nm) | <u>References</u> |
|--|-------------------|---|---|--|--|--|
| <u>ZnSnO₃</u> | <u>80</u> | <u>45</u> | <u>1</u> | <u>20</u> | <u>310</u> | <u>Minami, T. et al., JVST A 13(3), 1995</u> |
| <u>Zn₂SnO₄</u> | <u>92</u> | <u>570</u> | <u>0.058</u> | <u>19.0</u> | <u>620</u> | <u>Wu, X. et al., JVST A 15(3), 1997</u> |
| <u>Zn₂In₂O₅</u> | <u>95</u> | <u>2.9</u> | <u>6.0</u> | <u>30</u> | <u>400</u> | <u>Minami, T. et al., Thin Solid Films</u> <u>290-291, 1996</u> |
| <u>Zn₃In₂O₆</u> | <u>80</u> | <u>3.8</u> | <u>3.4</u> | <u>46</u> | <u>1400</u> | <u>Phillips, J. et al., Appl. Phys. Lett.</u> <u>67(15), 1995</u> |
| <u>MgIn₂O₄</u> | <u>85</u> | <u>20</u> | <u>1.8</u> | <u>15</u> | | <u>Minami, T. et al., Thin Solid Films 270,</u> <u>1995</u> |
| <u>MgIn₂O₄</u> <u>Zn₂In₂O₅</u> | <u>82</u> | <u>10</u> | <u>3</u> | <u>2</u> | <u>400</u> | <u>Minami, T. et al., ICMC TF, 1995</u> |
| <u>In₂O₃:Ga</u> | <u>85</u> | <u>5.8</u> | <u>5</u> | <u>20</u> | <u>400</u> | <u>Minami, T. et al., JVST A 15(3), 1997</u> |
| <u>GaInO₃</u> (Sn,Ge) | <u>90</u> | <u>29</u> | <u>4</u> | <u>10</u> | <u>1000</u> | <u>Phillips, J. et al., Appl. Phys. Lett.</u> <u>65(1), 1994</u> |
| <u>(GaIn)₂O₃</u> | <u>90</u> | <u>10</u> | <u>3</u> | <u>20</u> | <u>100</u> | <u>Minami, T. et al., JVST A 15(3), 1997</u> |



[0069] The amorphous structure and oxygen deficiency of the TCO theoretically allows the TCO coating to exhibit conductive properties and barrier properties similar to transparent dielectric barrier layers, such as nonstoichiometric types of silica or alumina. Also, because of the oxygen deficiency, ~~and amorphous structure,~~ the barrier layers gather the oxygen and keep the oxygen from passing through. Multiple thin layers of TCO function as both a transparent electrode and a transparent barrier layer. The benefit of using TCO alternating with metallic film layers, besides the beneficial barrier properties, is that all the layers of the structure are conductive, thus improving conductivity.

In the preferred embodiment, a suitable apparatus for coating the substrate with conductive and barrier layers is illustrated schematically in **FIG. 13**. All of the coating equipment is positioned in a vacuum chamber **36**. A roll of polypropylene, polyester or other suitable plastic sheet is mounted on a pay-out reel **37**. Plastic sheet **38** forming the substrate is wrapped around a first rotatable drum **39**, and fed to a take-up reel **41**.

[0070] A roller **42** is employed, as appropriate, for guiding the sheet material from the payout reel to the drum and/or to the take-up reel.

A flash evaporator **43** is mounted in proximity to the drum at a first coating station. The flash evaporator deposits a layer or film of monomer, typically an acrylate, on the substrate sheet as it travels around the drum. After being coated with a monomer, the substrate sheet passes a radiation station where the monomer is irradiated by a source **44** such as an electron gun or source of ultraviolet (UV) radiation.

[0071] The UV radiation or electron bombardment of the film induces polymerization of the monomer.

The sheet then passes coating station **46** where a coating of TCO is preferably applied by magnetron sputtering. The sheet then passes another flash evaporator **47** where another layer of monomer is deposited over the TCO layer. The sheet then passes radiation station **48** and the monomer is polymerized. Depending on whether a layer of monomer is above or below the TCO layer, either evaporator **43** or **47** is used.

[0072] Clearly, if the TCO layer is to be sandwiched between layers of polymer, both evaporators and their respective radiation sources are used. In addition to magnetron sputtering, the TCO layer ~~is~~ may be processed by one of thermal evaporation, chemical vapor deposition, plasma enhanced chemical vapor deposition, and electron beam evaporation.

Chemical vapor deposition is a high temperature process, and is therefore the least desirable for use with plastic substrates ~~but is acceptable for metal foil substrates.~~

[0073] In an alternative embodiment, a ~~LML~~liquid smoothing or hardcoat layer applicator **52** is mounted in proximity to the drum at a first coating station. The liquid smoothing applicator deposits a layer of monomer, e.g. acrylate, over the substrate. This layer of monomer is cured by irradiation from an ultraviolet or electron beam source **44** adjacent the drum (the positions of source **44** and applicator **52** are interchanged). Additionally, the sheet then passes coating station **46** where a coating of thin metal film, metal oxide, and/or metal nitride is applied by one of vacuum sputtering, vacuum metallizing, plasma assisted chemical vapor deposition, or electron beam evaporation. For example, silicon oxides is deposited by a plasma enhanced chemical vapor deposition process using a metal organic precursor and an oxidizing or inert carrier gas coating station **46** alternatively containing deposition sources.

[0074] The various layers described ~~are~~can be deposited in several processes; in addition to vacuum coating techniques. For instance, the layers ~~are~~can be deposited through ~~nonvacuum (atmospheric)~~ roll coating. ~~Alternatively or additionally~~Additionally, the layers ~~are~~can be deposited by an in line coating machine, whereby a conveyor belt runs the substrate to be coated past multiple coating stations. In a further alternative, the layers ~~are~~can be deposited by an intermittent motion machine, ~~that is either in a vacuum process or a nonvacuum process.~~ In yet another alternative, the layers are coated using a multitude of machines ~~and/or processes.~~ For instance, the plastic substrate ~~is~~can first be coated through atmospheric roll coating with a cured polymer and subsequently coated by vacuum deposition, or liquid coated, such as Gravure coating.

For multiple layers of organic polymer coatings deposited in the PML process, take up reel **41**, with the sheet wound thereon, functions as the pay out reel **37**, and the process is repeated as desired by coating in both directions. For this alternative, additional curing stations are mounted on the opposite side of evaporators **43** or **47**.

[0075] The roll of sheet is removed from the vacuum system for use.

FIG. 14a illustrates a laminating process for the FPD where plastic substrates, hardcoating, and a display medium are bonded together, ~~for example,~~ with an adhesive ~~and~~, pressure, ~~and~~ temperature or through UV radiation. **FIGS. 14b** and **FIG. 14c** are cross-sectional schematic views of the FPD before and after undergoing the bonding process,

respectively. The laminating process is one of the alternate methods for bonding the layers to construct the FPD. Because the layers of the present invention are thin, cracking, crazing, and delamination are avoided using processing methods of this type.

[0076] ~~FIGS. FIG. 14b and FIG. 14c~~ illustrate schematically the flat panel display with an exterior protective overcoat 4 and the display medium 2. ~~The display medium also may be liquid, or deposited over either substrate, or over a carrier film.~~

[0077] Transparent dielectric layers with good barrier properties and a high refractive index, such as metal oxides like titanium oxide or aluminum oxide, or metal nitrides such as silicon nitride or aluminum nitride, used in combination with thin, transparent metallic film layers provide a transparent conductive barrier coating. The metal oxide or metal nitride layers are deposited at specific thicknesses to optimize the optical performance (e.g. transmittance) of a particular display. Preferably, the thin metallic film layer is sandwiched in between layers of metal oxide or metal nitride. Multiple alternating layers of metal oxides or metal nitrides, with their barrier properties, and the highly conductive metallic film layers provide increased barrier performance and conductivity for a particular display medium.

[0078] The optical and electrical performance of transparent conductive oxide coatings are also improved by mildly heating the coated substrate during deposition or by post-annealing the coated substrate. As shown in the Experimental Results below, even though the PET substrate was heated to a moderate temperature of only 65°C, the resistivity of the ITO was still low enough to effectively operate as an electrode, because of the multiple thin layers of ITO.

In an alternative embodiment, the thin conductive metal nitride layer is substituted for one or more thin metallic film layers, for example, for the metal layers in the "optically enhanced metal" (see ~~Fig~~**FIG. 11**). Metal oxide or TCO layers are utilized with the metal nitride layer for enhancing both the optical and electrical performance characteristics.

[0079] Metal nitrides have good gas barrier properties. However, to achieve very low moisture (water vapor) and oxygen permeability, there is a minimum thickness of barrier material, e.g. the metal nitride layer. Because of the higher optical transparency silicon nitride thin films, for example, are attractive candidates for flexible FPD as barrier layers for atmospheric gases.

[0080] In another alternative embodiment, at least one of the metallic film layers in, for example, the "optically enhanced metal" is replaced with a polymer layer formed via the PML processes.

RESULTS OF CONDUCTED EXPERIMENTS

Results of Conducted Experiments

[0081] The plastic substrate for a flat panel display has a very low oxygen and water vapor permeability, a surface roughness much less than the barrier film thickness, a high Tg (the glass transition temperature) to allow a higher temperature and/or higher energy ITO deposition process, and a high transparency with low birefringence.

[0082] Defects in the coated layers limit the barrier properties. For instance, rough substrates, particulates, and roller contact, damage the coated layers. Rough substrates with thin film barriers are smoothed and prevented from damage by roller contact, with an organic basecoat and polymer top coat.

Multiple layers of TCO deposited on the substrate achieve lower surface resistivity than a single thick layer of TCO because the single layer cracks and/or crazes from stress. Further, the multiple TCO layers act as electrodes connected in parallel.

[0083] Using a non-stoichiometric dielectric of a group including silicon oxides, aluminum oxides, and silicon nitrides, allows for the fabrication of efficient thin film barriers for flexible plastic films.

[0084] Measured data for films made of sputtered ITO exhibited exceptional barrier properties. The optical, electrical and barrier properties were measured for ITO sputter-deposited directly onto a PET substrate, and also measured with a PML acrylic basecoat over the substrate before deposition of the ITO, in a roll-to-roll (web) coating process. See **FIGS. 15- through FIG. 18**, and the descriptions of these Figures below. The typical performance of a single ITO layer deposited on a basecoated PET substrate is 85%T (Transmittance) and ~~80 Ohms/Square~~ **80 ohms/square**. The ITO layer has a physical thickness of about 140 nm, for a one-half wave optical thickness, while the PET substrate has a thickness of about 0.007" ~~inches~~. For the single layer ITO film, oxygen permeability ranged from ~~0.005-0.005~~ to 0.05 oxygen cc/m²/day, while the water vapor permeability ranged from ~~0.005-0.005~~ to 0.05 g/m²/day.

FIG. 15 discloses a chart showing water vapor permeability of (1) ITO film deposited over the PET substrate, and (2) a PET substrate coated with "an optically enhanced metal" layer formed from an ITO film layer, a silver layer, and another ITO film layer, versus ITO film sheet resistance. No smoothing base coat was applied to the substrate in either case. The ITO layer was DC sputter deposited onto the PET substrate. ~~The deposited ITO film alone is reactively sputtered from a metal ceramic target in a web coater.~~ The solid vertical lines shown connect the midpoints of the range of permeability results at each measured resistance for the ITO film sheet. ~~The chart FIG. 15 shows that for the ITO film layer, the water vapor permeability dips to a minimal value of approximately 0.006 g/m² day at a resistance of about 60 Ohms/Square. ohms/square. The water vapor permeability reaches a maximum of approximately 0.21 g/m² day at a resistance of about 350 Ohms/Square.~~

[0085] ohms/square. For the silver layer in between the ITO film layers, the approximate water vapor permeability range was 0.04 to 0.075 g/m² day for the sheet resistance at about 12 Ohms/Square. ohms/square.

[0086] **FIG. 16** discloses a chart showing water vapor permeability of an (1) ITO film deposited over the PET substrate, and (2) a PET substrate coated with "an optically enhanced metal," layer formed from an ITO film layer, a silver layer, and another ITO film layer, versus ITO film sheet thickness. The parameters for the ITO layer alone ~~is~~ are analyzed in the same manner as above. ~~The chart FIG. 16 shows that for the ITO film layer, the water vapor permeability dips to a minimal value of approximately 0.006 g/m² day at an ITO a thickness of about 120 nm. The water vapor permeability reaches a maximum of approximately 0.21 g/m² day at an ITO a thickness of about 40 nm. For the substrate with the sandwiched silver layer in between the ITO film layers, the approximate water vapor permeability range was 0.04 to 0.075 g/m² day for a total ITO coating film thickness of approximately 120 nm.~~

[0087] **FIGs. 17 and FIG. 18** disclose charts showing oxygen permeability of ITO film deposited on a PET substrate versus ITO film thickness and versus sheet resistivity, respectively. **FIG. 17** shows that the oxygen permeability dips to a minimal value of approximately 0.017 g/m² day at an ITO thickness of about 220 nm. The oxygen permeability reaches a maximum of approximately 0.9 cc/m² day at an ITO thickness of about 40 nm.

[0088] ~~As shown in Table 1, alternating~~ Alternating barrier layers of PML deposited organic polymers and dielectrics have permeation rates below the limits of the instruments, which is 0.005 g/m² day for ~~Permatrana~~ PERMATRAN-W™ 3/31 instrument, which is ~~an instrument that measures water vapor transmission rates~~, and 0.005 cc/m² day for ~~Ox-Tran~~ OX-TRAN™ 2/20 instrument, which is ~~an instrument that measures oxygen transmission rates~~.

[0089] ~~The transparent dielectric barrier layer or the~~ a single layer of TCO deposited on the substrate ~~has suitable barrier properties for~~ meets the barrier requirements for some plastic FPD. ~~The preferable barrier properties~~ Barrier requirements vary by the type of display technology, e.g., liquid crystal display (LCD), organic light emitting display (OLED), ~~or~~ and thin film electro luminescent displays display (TFELD). The acceptable value of vapor permeation with plastic substrates for FPD depends on the sensitivity of the specific display technology utilized. For example, the LCD is much less sensitive to vapor permeation than the OLED or TFELD. For the LCD, maximum oxygen permeability is in the range of about 0.01 to 0.1 cc/m² day, while the maximum water vapor permeability is in the range of about 0.01 to 0.1 g/m² day. For both OLED and TFELD, permeabilities of $s \leq 0.001$ cc/m² day for oxygen, and $s \leq 0.001$ g/m² day for moisture (water vapor) are ~~preferred~~ required.

[0090] A polymer OLED and a small molecule OLED describe the two basic technologies for the layer that emits light in the OLED. For polymer ~~OLED's~~ OLEDs, the light emitting material is deposited by flow coating, spin coating, gravure coating, meniscus coating, curtain coating or any common liquid coating or printing techniques. ~~The small~~ Small molecule OLED is ~~normally thermally evaporated in a~~ OLEDs are typically vacuum deposited, but may also be processed with ~~nonvacuum~~ atmospheric coating methods. ~~When if the OLED is a polymer. When an ITO layer is deposited by nonvacuum processes such as by screen printing, the process of the present invention is entirely nonvacuum. Alternatively, the process of the present invention takes place by both vacuum and nonvacuum methods. Preferably, the process takes place entirely in a vacuum to avoid contamination by particulates, moisture and oxygen. Superior barrier films and other films result from~~ are provided by the cleaner vacuum process.

[0091] As shown in **FIGs. 15** and **FIG. 16**, and described above, for the LCD as long as the ITO sheet resistance is below about 250 Ohms/square, and the ITO film thickness is between about 75 and 225 nm, the water vapor permeability is within desirable limits for the an LCD. As shown in **FIG. 17** and **FIG. 18**, the oxygen permeability is within desirable limits for the an LCD as long as the ITO film thickness is above about 85 nm and the sheet resistance is below about 150 Ohm/square. Because of the lower permeabilities preferred required for the emissive displays (e.g. OLED and thin-film electro-luminescent displays), the barrier capability is enhanced by TFELD, multilayer dielectric or TCO barriers in combination with PML processed polymer coatings (i.e. composite barrier layers of PML deposited organic polymer layers, dielectric layers and/or TCO layers) are required.

[0092] Appendix D has two charts that illustrate Table B illustrates water vapor and-oxygen permeability versus ITO thickness— for semi-reactively sputtered ITO:

TABLE B
TRANSPARENT BARRIER COATINGS BASED ON
ITO FOR FLEXIBLE PLASTIC DISPLAYS
Experimental Results for ITO Barriers on PET
Semi-Reactively Sputtered

| <u>Total ITO</u> <u>Thickness</u> <u>(nm)</u> | <u>Surface</u> <u>Resistivity</u> <u>(ohms/square)</u> | <u>Rho</u> <u>(x10⁻⁴</u> <u>n-cm)</u> | <u>%T vis</u> <u>(Luminous)</u> | <u>H₂O</u> <u>Permeance</u> <u>(cc/m²-day)</u> | <u>O₂</u> <u>Permeance</u> <u>(g/m²-day)</u> |
|--|---|---|--|---|---|
| <u>123.3</u> | <u>38.3</u> | <u>4.685</u> | <u>84</u> | <u>0.038</u> | <u>0.827</u> |
| <u>172.4</u> | <u>29.9</u> | <u>5.145</u> | <u>82</u> | <u>0.073</u> | <u>1.19</u> |
| <u>299.2</u> | <u>17.2</u> | <u>5.15</u> | <u>~81</u> | <u>0.049</u> | <u>0.081</u> |
| <u>49.9</u> | <u>188.4</u> | <u>9.4</u> | <u>~81</u> | <u>0.036</u> | <u>0.156</u> |
| <u>218.5</u> | <u>31.8</u> | <u>6.94</u> | <u>~80</u> | <u>0.0621</u> | <u>0.038</u> |
| <u>117.05</u> | <u>57.48</u> | <u>6.64</u> | <u>~82</u> | <u>0.12</u> | <u>0.0246</u> |
| <u>74.3</u> | <u>348.5</u> | <u>25.6</u> | <u>~86</u> | <u>0.2375</u> | <u>0.8625</u> |

[0093] The measured results for semi-reactively and reactively sputtered ITO, as well as the differences between a single ITO layer and two ITO layers (with a polymer layer in

between the two layers) made with a semi-reactive process, are illustrated ~~and in tabular form.~~
~~'Semi-reactively' sputtered in FIG. 19 and FIG. 20. "Semi-reactively sputtered"~~ refers to
films, DC magnetron sputtered from a ceramic target. ~~The differences between the two~~
~~processes are believed to~~

The preferred thickness for ITO is different for conductivity and barrier properties.
The film thickness must be due to the specific process parameters, and greater to have
conductive properties. Also, if the layer is too thin it will not inherent to the process type. As
shown, for the same total thickness deposited by the same reactive process, two ITO layers
have higher conductivity and lower permeability as compared to the single ITO layer.
Further, the two ITO layers have higher electrical performance, because the single ITO layer
cracks and/or crazes.

[0094] The preferred thickness for the deposited barrier properties. The critical thickness
for these layers varies with the material and how the layers is different for conductivity
properties than for barrier properties. The thickness of the deposited film is related to the
film's conductive and barrier properties. The critical thickness for barrier properties of these
layers varies with the material and, to a lesser extent, how the layer is are deposited. For ITO,
the critical minimal thickness is about 20-10 nanometers (or 200-100 angstroms), minimum.
The lower thickness-limits for some of the metal oxides which are typically used in packing
applications is in about the 10 to 30 nanometer range. Generally, 5-10 nanometers in
packaging. Generally, 5-10 nanometers is the minimum thickness ~~thickness~~ required for
adequate barrier properties. ~~Enhanced conductive properties result from film thicknesses in~~
the range of about , however, the film needs to be thicker for conductivity properties (20
nanometers to 300 nanometers). If the single-layer film is thicker than that range, then the
film starts cracking, and hence, loses conductivity ~~and barrier properties.~~ For maximizing
single-layer optical transmission, it is well known that ~~certain optical thicknesses, e.g. one-~~
half wave, of thin films are can be selected. The typical physical thickness is ~~in the range of~~
about 20 to 300 nanometers for ITO on a flexible substrate.

~~FIGS. 20-23 are charts showing transmittance and reflectance spectra versus~~
~~wavelength for an ITO layer deposited over a PET substrate at a sheet resistance of 29~~
~~Ohms/Square, 57 Ohms/Square, 65 Ohms/Square, and 347 Ohms/Square, respectively. As~~
~~shown, generally, for a range of the .~~ **21** and **FIG. 22** show that PET substrates have lower

sheet resistance and resistivity for the same oxygen flow rates than a glass substrate. **FIG. 21** discloses a chart showing sheet resistance, the percentage of spectral transmittance and reflectance remains relatively constant. For example, at about a wavelength of 500 nm, the transmittance percentage is about 80% for resistance ranging from 29 Ohms/Square to 347 Ohms/Square. DC sputter deposited ITO on a hardcoated PET substrate exhibited a sheet resistivity of 46.9 Ohms/Square, which is a volume resistivity of approximately 5×10^{-11} Ohm-cm, and a visible transmittance of about 84.7%. Generally, the transmittance increases (and the reflectance decreases) as the plasma wavelength increases. There is always a compromise between high optical transmittance and high conductivity.

In contrast to Figs. 20-23, in FIG. 19 the transmittance decreases and the reflectance increases at the higher wavelengths. FIG. 19 is a chart showing transmittance and reflectance spectra versus wavelength for a more preferred embodiment of the present invention. Fig. 19 shows the transmittance spectra for a of various substrates versus oxygen flow rate through the respective substrate. Substrates of PET-substrate, hardcoated PET (a PET coated with layers of an ITO, silver film, and another ITO at a sheet resistance of 14 Ohms/Square. **[0095]** Appendix E illustrates the Transmittance and Reflectance of semi-reactively sputtered ITO on a PET substrate for various thicknesses versus wavelength. The transmittance and reflectance of a substrate coated with a polymer layer and a base coat that is liquid smoothed/atmospheric coated for surface abrasion resistance), and glass were compared. Glass has the highest sheet resistance, especially at oxygen flow rates over 3 sccm (standard cubic centimeters per minute). The chart shows that the glass sheet resistance reached approximately 500 ohm/square at an ITO layer, a substrate with oxygen flow rate of 5 sccm. At the same oxygen flow rate, PET and hardcoated PET have approximately the same sheet resistance. The least sheet resistance (35 ohms/square) for the PET substrates is at an ITO layer, and a substrate with two ITO layers (with a polymer layer in between the two ITO layers) are illustrated. Generally, transmittance and conductivity are inversely related. Improved optical performance is achieved by controlling the thickness and index of the polymer layers. oxygen flow rate of 2 sccm, while the highest sheet resistance (170 ohms/square) is at an oxygen flow rate of 5 sccm. FIG. 22 shows similar results for resistivity.

[0096] For a transparent electrode, conductivity specifications varies with display technology and addressing method. The surface resistivity for LCD's is about 50-300 Ohms/Square, and **FIG. 23** and **FIG. 24** disclose charts showing sheet resistance and resistivity, respectively, of various substrates versus oxygen flow rate through the respective substrate, where 7.5% of the plasma used in the sputtering process is hydrogen gas. Substrates of PET, hardcoated PET, and glass were compared. Again, glass has higher sheet resistance and resistivity, especially at oxygen flow rates over 3 sccm. The chart shows that at an oxygen flow rate of 5 sccm, the glass sheet resistance reached approximately 350 ohms/square and a resistivity of approximately $27 \text{ ohm-cm} \times 10^{-4}$. PET and hardcoated PET have approximately the same sheet resistance and resistivity for the same oxygen flow rate. The least sheet resistance (40 ohms/square) for these PET substrates is at an oxygen flow rate of approximately 2.3 sccm, while the highest sheet resistance (150 ohms/square) is at an oxygen flow rate of 5 sccm.

[0097] **FIG. 25** and **FIG. 26** disclose charts showing sheet resistance and resistivity, respectively, of various substrates versus oxygen flow rate through the respective substrate, where 20% of the plasma used in the sputtering process is hydrogen gas. Substrates of hardcoated PET and glass were compared. Again, glass has higher sheet resistance and resistivity, especially at oxygen flow rates below 2 sccm and over 5-6 sccm. The oxygen flow rate for the hardcoated PET substrate did not exceed 6 sccm. Generally, the sheet resistance and resistivity are significantly lower for OLED's is about 10-100 Ohms/Square the increased percentage of hydrogen in the plasma, for oxygen flow rates above 3 sccm.

[0098] **FIG. 27** is a chart showing transmittance and reflectance spectra versus wavelength for a more preferred embodiment of the present invention. **FIG. 27** shows the transmittance spectra for a PET substrate coated with layers of ITO, silver film, and ITO at a sheet resistance of 14 Ohms/Square. **FIG. 28** through **FIG. 31** are charts showing transmittance and reflectance spectra versus wavelength for an ITO layer deposited over a PET substrate at a sheet resistance of 29 Ohms/Square, 57 Ohms/Square, 65 Ohms/Square, and 347 Ohms/Square, respectively. As shown, generally, for a range of sheet resistances the percentage of spectral transmittance and reflectance remains relatively constant. For example, at about a wavelength of 500 nm, the transmittance percentage is about 80% for resistance ranging from 29 ohms/square to 347 ohms/square. DC sputter deposited ITO on a hardcoated

PET substrate exhibited a surface resistivity of 46.9 Ohms/square, which is a volume resistivity of approximately 5×10^{-4} Ohm-cm, and a visible transmittance of about 84.7%. Generally, the transmittance increases (and the reflectance decreases) as the plasma wavelength increases. There is always a compromise between high optical transmittance and high conductivity. In contrast to FIG. 28 through FIG. 31, in FIG. 27 the transmittance decreases and the reflectance increases at the higher wavelengths.

[0099] FIG. 32 through FIG. 36 illustrate transmittance and reflectance of semi-reactively sputtered ITO on a PET substrate for various thicknesses versus wavelength. The transmittance and reflectance of substrates coated with a polymer layer and an ITO layer are illustrated in FIG. 32 and FIG. 33. The transmittance and reflectance of a substrate coated with an ITO layer is illustrated in FIG. 34. The transmittance and reflectance of substrates coated with two ITO layers (with a polymer layer in between the two ITO layers) are illustrated in FIG. 35 and FIG. 36. Generally, transmittance and conductivity are inversely related.

[0100] For a transparent electrode, conductivity requirements vary with display technology and addressing method. The surface resistivity for LCDs is about 50-300 Ohms/square, and for OLEDs is about 10-100 Ohms/square. The corresponding visible transmittance for LCD's LCDs is about 90%, and for OLED's OLEDs is about 80-85%. The thickness of the conductor layer is compatible with the vacuum-web coating-processing for the flexible plastic substrate.

[0101] Table 1 shows the test results for oxygen and water vapor transmission rates of various samples of a PET substrate coated with a single ITO layer with different Ohms/Squaresquare coatings and a substrate coated with an ITO layer, a metal layer, and another ITO layer. The test conditions were as follows: the temperature was at 23°C-/73.4°F. On each side of the barrier for the oxygen transmission rate tests, the relative humidity was 0%. On one side of the barrier for the water vapor transmission rate tests, the relative humidity was 100%, but the other side of the barrier had a relative humidity of 0%.

[0102] The first eight samples of Table 1 are of a plastic substrate coated with a single ITO film layer, each with different nominal-ITO thickness and sheet resistances. For example, the '25-1' "25-1" is the first sample with a sheet resistance of 25 Ohm/square; whereas '25-2' "25-2" is the second sample from the same lot. The last two samples are of a substrate coated with an ITO layer, a metal coating, and another ITO layer, with a nominal

sheet resistance of 10 Ohm/square. This 3 layer configuration is the "optically enhanced metal," or "induced transmission filter," and has similar characteristics to a single TCO layer. With the optically enhanced metal, good conductivity, transmission and barrier properties are achieved. Preferably the ITO layers, which antireflect the metal, each have a layer has a thickness of about 3050-60 nanometers. In several instances, the samples were tested two times. For example, the second column for the 25 and 60 Ohms/Squaresquare samples reflects the results of the second test.

Although the present invention has been described and is illustrated with respect to various embodiments thereof, it is to be understood that it is not to be so limited, because changes and modifications may be made therein which are within the full intended scope of this invention as hereinafter claimed. In particular, the structure disclosed in the present invention for flat panel displays is schematic for LCD and other display technologies, such as polymer organic light emitting diode (POLED), small molecule organic light emitting diode (OLED) displays, and thin film electro luminescent.

Table 1

| Sample | Water Vapor Transmission Rate (g/m ² day) | | Oxygen Transmission Rate (cc/m ² day) | |
|--------|---|---------------------|---|-------|
| | | | | |
| 25-1 | 0.026 | <0.005 ¹ | 0.017 | 0.087 |
| 25-2 | 0.097 | <0.005 ¹ | 0.584 | 0.257 |
| 60-1 | 0.042 | | 0.059 | 0.071 |
| 60-2 | 0.050 | | 0.204 | 0.090 |
| 60-3 | 0.007 | | <0.005 ² | |
| 60-4 | <0.005 ¹ | | 0.014 | |
| 300-1 | 0.243 | | 0.861 | |
| 300-2 | 0.232 | | 0.864 | |
| M-10-1 | 0.076 | | 0.035 | |

| | | | | |
|--------|-------|--|-------|--|
| M-10-2 | 0.041 | | 0.024 | |
|--------|-------|--|-------|--|

1 The actual water vapor transmission rate was at least as low as the lower limit of the PERMATRAN-W 3/31 instrument, ~~Permatran W 3/31~~, 0.005 g/m² day.

2 The actual oxygen transmission rate was at least as low as the lower limit of the OX-TRAN 2/20 instrument, ~~Ox-Tran 2/20~~, 0.005 cc/m² day.

[0103] Table 2 compares permeation rates for different coatings, including multiple dyad (an acrylate/oxide pair) layers on the polyethylene terephthalate (PET) substrate, and coatings on oriented polypropylene (OPP) substrates. As shown, a single dyad on a substrate has high oxygen and moisture permeation resistance. In some instances, two oxygen transmission rate tests were conducted, and the results were shown in a second column. Footnote ¹ denotes the first row provides typical permeation rates for the PET substrate.

Table 2

| Sample | Water Vapor Transmission Rate (<u>0g/m² day</u>) | | Oxygen Transmission Rate -(cc/m ² day) |
|---|---|--|---|
| 2 mil PET | 30.5, 272 ¹ per micron film thickness | 5.3, 1550 ¹ per micron film thickness | |
| <u>2 mil PET</u> | <u>5.3 (272 per micron film thickness)</u> | | <u>30.5 (1550 per micron film thickness)</u> |
| Food packaging - target values (PET/oxide) | 1.55 | 1.5 | <u>1.55</u> |
| 2 mil PET/single dyad (23°C) | <u><0.007803</u> | 0.03 | <u><0.0078</u> |
| 2 mil PET/ seven dyads (23°C) | <u><0.0078016</u> | <u><0.016</u> | <u><0.0078</u> |
| 7 mil PET/ hardcoat (23°C) | <u>7.6</u> | - | <u>7.6</u> |
| 7 mil PET/ hardcoat/ single dyad (38°C) | <u><0.0078, 90% Relative Humidity (RH), 100% O₂ 0.2682, 100% RH</u> | <u>0.2682, 6061, 100% RH</u> | <u>≤0.6061, 0078, 90% Relative Humidity (RH), 100% RH O₂</u> |

| | | | |
|---|--|---|--|
| 7 mil PET/ hardcoat/ single dyad/ ITO (38°C) | ≤0.0078, 90% RH, <u>0098,</u> 100% Θ_2 -RH | 0.0098, <u>0128, 100%</u> RH | ≤0.0128, 0078, 90% RH, 100% RH $\underline{O_2}$ |
| PET/oxide | 0.7-1.5 <u>15-0.9</u> | 0.15-0.9 | <u>0.7-1.5</u> |
| PET/ <u>Aluminum</u> | <u>0.617</u> | 0.17 | <u>0.6</u> |
| OPP, copolymer, 1 mil | 1800 <u>1.3</u> | 1.3 | <u>1800</u> |
| OPP/ oxide | 17-546 <u>0.08-0.4</u> | 0.08-0.4 | <u>17-546</u> |
| OPP/ <u>Aluminum</u> | <u>200.11</u> | 0.11 | <u>20</u> |

[0104] Although the present invention has been described and is illustrated with respect to various embodiments thereof, it is to be understood that it is not to be so limited, because changes and modifications may be made therein which are within the full intended scope of this invention as hereinafter claimed. In particular, the structure disclosed in the present invention for flat panel displays can also be used with other display technologies, such as polymer light emitting diode (PLED) and light emitting diode (LED) displays.

TRANSPARENT CONDUCTIVE OXIDES FOR PLASTIC FLAT PANEL DISPLAYS

ABSTRACT

[0105] ~~A lightweight, flexible, plastic substrate used to construct displays, including flat panel displays, to package materials and for electro luminescence lamps is coated with at least one layer, such that the substrate has desired barrier and electrode characteristics. An electronic device on a plastic substrate, at least one side of the device being protected from reaction with or incorporation of moisture by a composite barrier. The display medium of the flat panel display is protected from oxygen and moisture in order to avoid degradation with the coating. The layer with composite barrier and electrode characteristics has both a low enough resistance to function as an electrode for the display, and low oxygen and moisture permeability. For lower permeability and/or higher conductivity may contain, for example, multiple alternating layers of transparent conductive oxide separated by one or more vacuum-evaporated in-situ polymerized organic layers, or may contain multiple barrier materials and conductive materials are applied. The barrier material includes at least one of a thin metallic film, an organic polymer, a thin transparent dielectric, a thin layers of transparent conductive oxide, transparent metal, or transparent conductive metal nitride, and a thin transparent conductive oxide. The conductive material includes at least one of a thin transparent conductive oxide, a thin transparent metallic film, and a thin transparent metal nitride. Preferably there is a Polymer Multi Layer (PML) processed base coat deposited over the substrate. The base coat produces substrate smoothing, and more importantly, in combination with another layer, the base coat improves vapor barrier properties. In the preferred embodiment, a PML processed top coat barrier layer is deposited before the coating contacts a surface, such as a roller. The PML processed top coat also excludes moisture (water vapor) and atmospheric gases that chemically degrade the device performance separated by at least one layer of organic dielectric polymer.~~